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14. ABSTRACT
DTAGs have proven to be a valuable tool for the study of marine mammal acoustics and fine scale motion. The success of the DTAG has resulted in an increased demand for the instrument from researchers both within the Navy and the marine mammal community as a whole. However, the current DTAG design has cost, robustness, and reliability issues that make it unsuitable for the scaled-up manufacturing necessary to meet demand. Here we propose to make design changes to improve reliability and manufacturability of the tag, and to test the new design by fabricating a small number of tags for testing. The project will result in a field-ready and cost-effective DTAG design.

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Finalizing the Dtag: implementation and testing of design improvements for reliability and availability

K. Alex Shorter,
University of Michigan,
Ann Arbor, MI 48104

Tom Hurst,
Woods Hole Oceanographic Institution,
Woods Hole, MA 02543

Mark Johnson,
Sea Mammal Research Unit, University of St. Andrews,
Gatty Marine Laboratory, St Andrews, Fife KY16 8LB UK

Contact: K. Alex Shorter - phone: 734.764.8449
Email: kshorter@umich.edu

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LONG-TERM GOALS

Here we propose to make design changes to improve reliability and manufacturability of the Dtag, a sound recording multi-sensor tag. Additionally, we will set up a lease pool that will be used to provide the community with access to tags at a moderate cost per project while also allowing for monitoring of tag field performance. Feedback from performance in the field will be used to continuously monitor and improve the tag design. \

OBJECTIVES

Dtags have proven to be a valuable tool for the study of marine mammal acoustics and fine scale motion. The success of the Dtag has resulted in an increased demand for the instrument from researchers both within the Navy and the marine mammal community. However, the current Dtag (DTAG3 V1.0) design has cost, robustness, and reliability issues that make it unsuitable for the scaled-up manufacturing necessary to meet demand, Figure 1. To address this, we will **A)** improve reliability and manufacturability of the tag, and **B)** evaluate the new design by fabricating a small number of proto-type tags for testing. Additionally, this project will **C)** implement these design changes to create a pool of field-ready and cost-effective Dtags available to marine mammal researchers. A fourth goal, **D)** the design and fabrication of a robust stand-alone archival sensing unit for an ARTS compatible tag system, was added during the execution of the project.

APPROACH

The objective of the DTAG3 V1.0 design was to expand the capabilities of the Dtag-2 (longer duration, wider bandwidth, support for more sensors) while decreasing the size of the instrument to make it suitable for smaller delphinids. The new design was also needed because Dtag-2

components had become obsolete. To meet the challenge of reducing size while increasing capabilities, we explored several different packaging methods. Unfortunately, some of these new compact fabrication methods have decreased the robustness of the system leading to tag failures in the field. This project involves four tasks to be performed over the course of two years. They are: **1)** implementation of design changes to address tag failure modes; **2)** improved design for manufacture; **3)** a small test build (4 units) of the new Dtags, which will be tested rigorously; and **4)** the fabrication of a quantity of the revised tags for use by the marine mammal science community via a lease pool. The development of this pool will alleviate the current Dtag availability bottleneck while providing a mechanism to incorporate experience from the field about long-term reliability of the tags.

YEARLY WORK COMPLETED

I. Design Changes to Address Tag Reliability

Objective: We continued to refine the tag design to improve the robustness and manufacturability of the design. Tags based on the design modifications described in the previous report were implemented on a subset of the pool tags (DTAG3x - Prototype) and tested in the field in and around Norway with Sperm whales and off the cost of Southern California with fin whales, blue whales, and Risso's dolphins. Feedback from the field has been used to refine the antenna and connector designs for the remaining pool tags (DTAG3x V1.0) in the design-iterate-build model proposed for this work. The updated design solutions to the original key limitations are presented below.

Methods and Results:

1. Problem: Sea water ingress. Potential leakage points in the external urethane shell have been identified in the current DTAG3 V1.0 design (e.g. all DTAG3s used before 2015). These primarily arise from components which necessarily penetrate the barrier such as the salt-water switch, the release wiring and the USB connector. Flexure of the shell when the tag is attached to a swimming animal gradually weakens the bond at these joints opening ingress paths for water. Once water has penetrated this barrier, inconsistent bonding of the urethane shell to interior wires and metal shield layers leads to water movement into the electronics cavity, battery and external USB connector causing failure of one or more of these subsystems.

Solution: Internal mechanical elements have been redesigned to simplify assembly and reduce exposed wiring and electronics. The USB connector and VHF circuitry are now located on the electronics sub-assembly and directly connected to the main tag electronics through pin headers and interface boards, Figure 2 bottom left. These changes eliminate the extended wiring that made assembly difficult and created leakage pathways. Multiple water barriers are now used to enhance the encapsulation of the electronics. The electronics are first sealed in a low viscosity casting resins (epoxy) and the sensor assembly and battery are encased in a layer of urethane, Figure 2. Next, the entire assembly is cast in a second layer of urethane that also serves as the overall tag housing.

2. Problem: Pressure tolerance of the electronics. The DTAG3 V1.0 used an oil or gel-filled bladder to create a pressure tolerant environment for the tag electronics. The oil/gel floods the space around the electronic components and is essentially incompressible so that, even though the components experience ambient pressure, there are no shear stresses due to pressure differences. A drawback of an oil-filled housing is that, if water is able to enter the housing, it

will contact the circuit causing corrosion and eventual failure. This was a significant cause of failure in the Dtag-2. The initial Dtag-3 design also used oil but due to manufacturing difficulties related to the smaller dimensions of the new tag, this was later changed to a two-part polyurethane gel. However the mixed resin was found to be too viscous to flow completely under the miniature tag components, resulting in electronic component failure at pressure.

Solution: A low viscosity epoxy casting resin together with vacuum investment is used to ensure that electronic components are fully encapsulated, Figure 2. The fully cast electronic system will be impervious to water and pressure tolerant. One important consideration in moving to epoxy encapsulated Dtag electronics was placement of the pressure transducer used to measure the location of the tag in the water column. Moving from an oil-filled to epoxy encapsulated electronics cavity required relocating the pressure transducer. To accommodate the rigid low-viscosity casting materials and relocation of the pressure transducer, we have created a separate external sensing module consisting of the hydrophones and pressure sensor. The sensor module is encapsulated in urethane and connected to the electronics through a header and interface board at the front of the tag, Figures 2 and 6. The solution has performed well in evaluations both in the lab and field. Extensive lab based pressure testing was used to test the fabrication strategy and to calibrate the pressure sensor (see the 2015 yearly progress report). Additionally, DTAG3x – Prototype tag assembles were fabricated and successfully tested in the field **(**See Section IV**).**

3. Problem: Floatation. Due to the replacement of oil with a higher specific gravity encapsulant, the current Dtag-3 no longer floats reliably in fresh or brackish water. Although the tag is usually used at sea, the lack of floatation could be an issue if the tag released from an animal in a region with a low salinity surface layer e.g., from a river outflow. Low buoyancy also affects the stability of the tag when it is floating at the surface leading to intermittent reception of the VHF beacon in the tag in high seas.

Solution: The volume of floatation has been increased through the re-design of both the syntactic foam and the external shell, Figure 3. This re-design will be closely integrated with the other modifications listed here to ensure that the final device is at least +10g positively buoyant in sea water.

4. Problem: Light sensitivity. Some of the miniature electronic components used in the tag are susceptible to light. In particular, fluctuating light levels cause large step changes in the pressure and magnetic field signals which are difficult to remove in post-processing. As the casting materials used for the external shell are translucent, the tag data can be strongly affected by light when the animals are near or at the surface.

Solution: Susceptible parts will be replaced with components that are not light sensitive. However, to avoid any other problems of this kind, we will manufacture the external tag structure from a material that blocks out light, Figure 4.

5. Problem: Hydrophone vulnerability. Front mounted spherical hydrophones have failed following field deployments. These failures are likely the result of a direct impact to the exposed sensor while the tags are being handled. Hydrophone failures were not an issue with the Dtag-2 design because the sensors were more centrally located and the external polyethylene shell that formed the tag housing provided an additional layer of protection. However, the polyethylene reduced sensor performance, because air trapped between the shell and the sensor blocks sound when the animal is close to the surface. The polyethylene shell was eliminated in the DTAG3 V1.0 design to improve acoustic performance, but the hydrophones are more vulnerable as a result.

Solution: External housing material around the hydrophones has been increased, Figure 4.

6. Problem: Connector robustness and functionality.

The DTAG3 V1.0 connector design was located on the foam away from the tag electronics and created leakage pathways that lead to a number of tag failures. The DTAG3x – Prototype design used an external PCB board and plastic socket to form the tag side of the connector. While this design was an improvement, users still experienced intermittent connectivity issues during tag communication and offload.

Solution: To improve the robustness of the connector the current design now uses a pin header directly connected to the main electronics board. The header is first waterproofed with an epoxy and then mounted to the electronics, Figure 2. A mating socket is used to improve connector connectivity and provide the mechanical feature for a protective plug that will limit the connectors exposure to the marine environment.

7. Problem: Antenna Robustness: The DTAG3x - Prototype antenna design was changed from a single length of nicrome wire to a coil antenna with a rigid structural core. The coiled antenna began at the end of the foam and continued up the length of the rigid core, and the length of the antennas was tuned to the tag specific VHF circuit. While this improved the design and transmission efficiency of the antenna, the rigid carbon fiber cores were broken on multiple occasions in the field.

Solution: The rigid core and antenna coil have been replaced by a single length of stainless steel braided wire. The wire is connected mechanically to the antenna loop on the foam using a crimp at the tip of the foam, Figure 3. The length of the antenna will still be tuned to maximize the performance of each specific tag.

II. Design for Manufacturability

Objective: A key to reducing the overall cost of the tag and improving tag reliability is enhanced design for manufacturability.

Methods and Results: We have divided the current single unit approach into 3 main sub-assemblies (Figure 5): 1) foam sub-assembly, 2) sensor sub-assembly, and 3) Electronics sub-assembly. This separation enables rapid quality assurance on individual sub-assemblies, leading to improved yield, increased throughput, and reduced cost. The foam sub-assembly is made up of the tag floatation, the VHF antenna assembly, and the saltwater switch. The sensor sub-assembly contains the two hydrophones, the external pressure sensor, and an interconnect board. The electronics sub-assembly consists of the main electronics, a protective mechanical structure, the release, and the USB connector for data offload and recharge.

The use of interconnect boards and pin headers to replace the intricate wiring of the single unit DTAG is key to this modular design. The improved connections between the subassemblies eliminate leakage pathways that had resulted in tag failure while also reducing tag assembly times. The three sub-assemblies have been designed to operate as individual units for stand-alone testing, reducing bench testing times. The identification of performance problems with individual units before final assembly will enhance the overall manufacturing yield.

The components have been designed and selected with scaled up manufacturing in mind. Individual components that make up the sensor module, for example, are assembled by outside vendors. The interface board comes populated from the board house and the hydrophone spheres

come wired and assembled. Further we have been working with external vendors (1900 Engineering, LLC), on large volume encapsulation of the sensor sub-assembly.

III. DTAG3 Core Units: Along with the design, testing, and fabrication of the robust and manufacturable DTAG (the DTAG3x) we worked successfully with Dr. Patrick Miller and colleagues at the University of St. Andrews to design a separate tag system that will be compatible with the Aerial Rocket Tag System (ARTS). While the design of the DTAG3x V1.0 has been focused on the integration of tag components to optimize packaging efficiency and reduce the overall tag size, the design of the DTAG3-Core was focused on the creation of a robust stand-alone archival sensing unit that could be deployed in the marine environment, Figures 1 and 7. This work was motivated by the need to develop a DTAG3 compatible system for the ARTS pneumatic launching system for tag deployment in certain field situations. The DTAG3-Cores are designed around the DTAGx V1.0 electronics, Figure 6, and leverages many DTAG3x V1.0 design elements including the release and housing. As with the DTAG3x V1.0, a low viscosity epoxy casting resin together with vacuum investment was used for electronics encapsulation. The improved connector design and opaque urethane housing described in Section 1 were also used with the DTAG3-Core tags, Figure 7. Dr. Miller and his team designed an alternative housing system for the Core units. The housing system included the floatation, VHF transmitter, suction cups, and the interface with the ARTS system.

IV. Field Testing: Field trials have been conducted with both Core units (Figure 7) and DTAG3x-Prototype tags (Figure 8) built using the design concepts presented in Section I. The field work was conducted by Dr. Patrick Miller at two field sites: off the coast of Norway tagging sperm whales with the DTAG3x-Prototype tags and around Jan Mayen with the Core units focused on bottlenose whales. Additional field work was conducted by Dr. Brandon Southall and John Calambokidis off the coast of southern California as part of the SOCAL-BRS project. During the SOCAL work the DTAG3x-Prototype tags were used to tag Risso's dolphins, fin whales, and blue whales. The tags successfully collected data during all trials, and no tags were lost during the experimental work. However, the researchers reported occasional connectivity issues with the USB connector and the VHF antenna core was broken on tags during both experiments. These issues with early prototypes have been addressed (See Section 1) in the final tag design and will be implemented with the remaining pool tags that are currently being fabricated. We have also set up a database containing details of problems identified in the field. This direct information from users in the field will be used to continually improve the design of the DTAG and monitor resulting performance.

VI. Fabrication and implementation of the Tag Pool: To date we have fabricated three DTAG3x-Prototype tags and four DTAG3-Core units. These tags were made avalible for the field work described in Section IV using the month-to-month leasing model outlined in the proposal. Feeback from the field deployments has been used to revise the design for the remaining tags that we will build for the pool. We are currently planning on building eight more DTAG3x V1.0 tags by the end of the year and will have 15 tags avalible to support field efforts in 2017 (11 standard DTAGs and 4 Core units). The goal of the lease program is to become self-sustaining. To this end demand for tags and feedback from from the community will be used to refine the business model to achieve the duel goal of providing affortable tags to the community while achieving sustainability.

FIGURES:

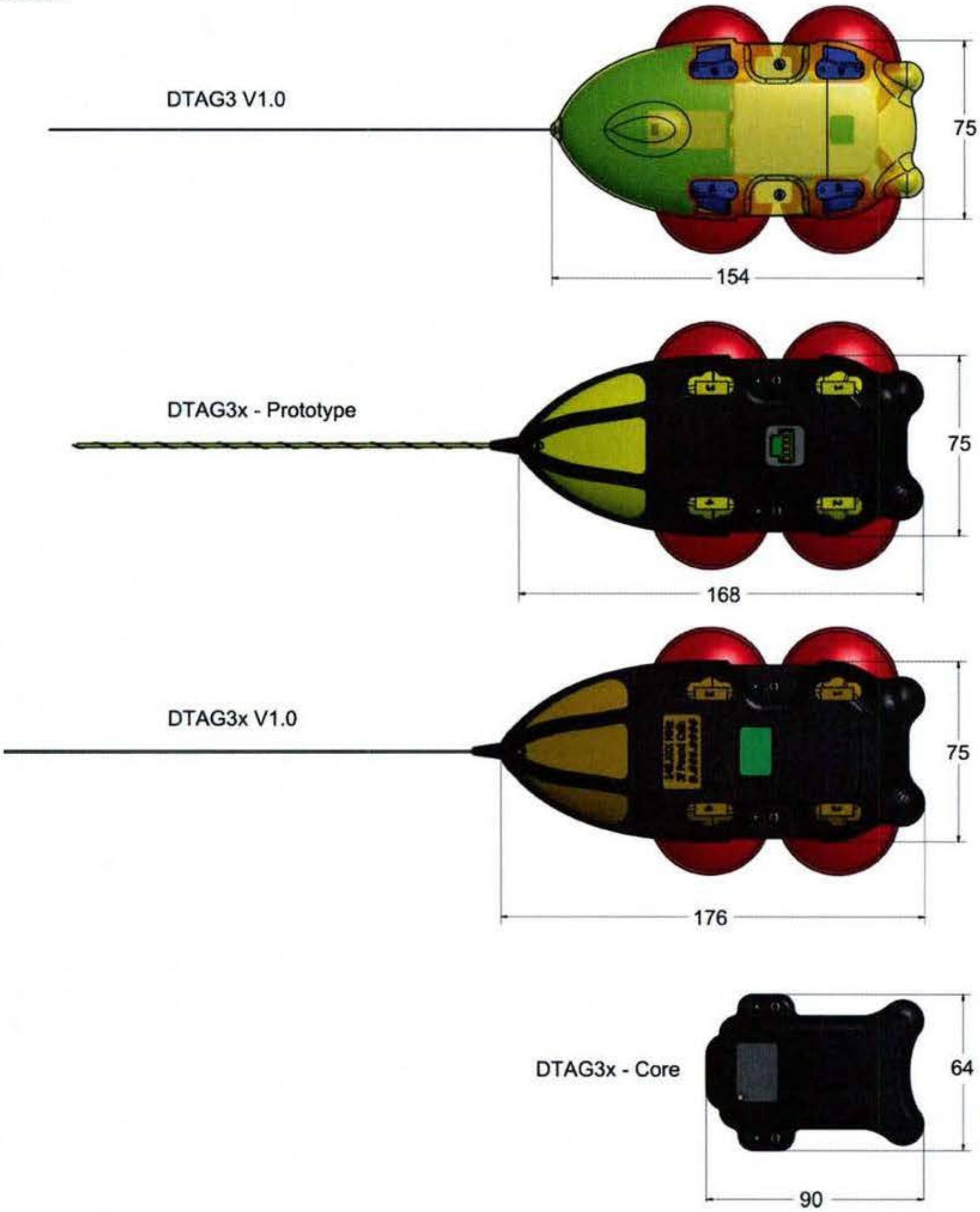

Figure 1 A comparative illustrations of the DTAG3 designs discussed in this report. The ***DTAG3 V1.0*** is the design currently used for the WHOI pool tags. The ***DTAG3x-Prototype*** design addresses the original five identified issues with the ***DTAG3 V1.0*** (Section 1, Problems 1-5). The ***DTAG3x V1.0*** design incorporates feedback from the users about connector and antenna robustness issues identified during 2016 field work (Section 1, Problems 6-7). The ***DTAG3x–Core*** design is a robust stand-alone archival sensing unit that was a key component for an ARTS compatible tag system developed with collaborators at St. Andrews University. Dimensions in (mm).

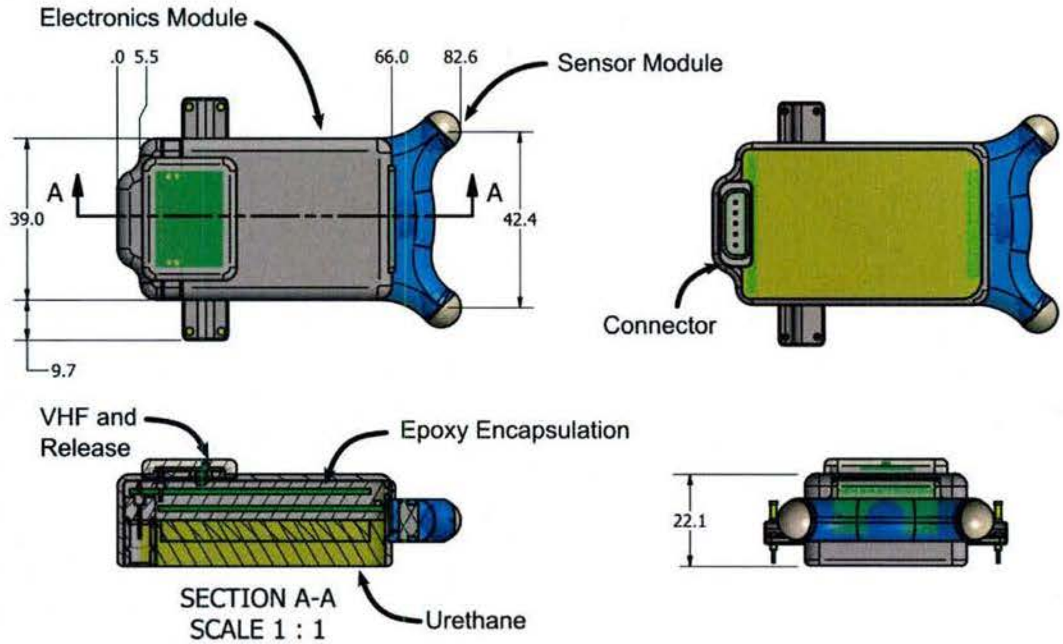

Figure 2 A drawing of the electronics and sensor sub-assemblies that illustrates the low viscosity epoxy and urethane used to provide pressure compensation and waterproofing. Dimensions in (mm).

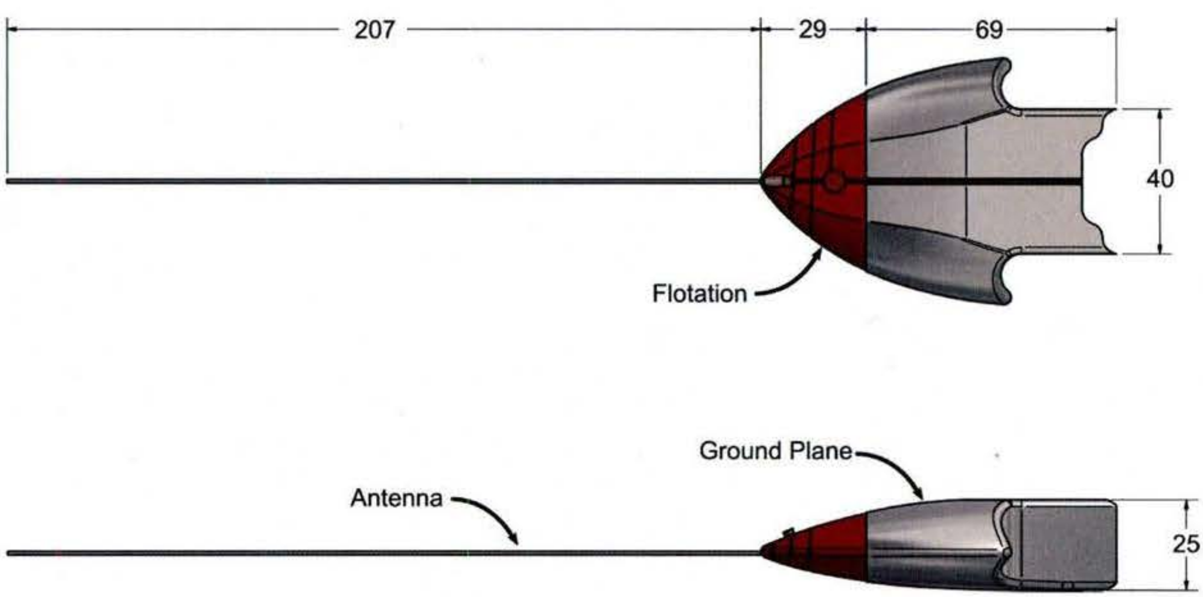

Figure 3 A drawing of the foam sub-assembly shown with the VHF antenna wire and ground plane. Syntactic foam is be used for the floatation. All dimensions in (mm).

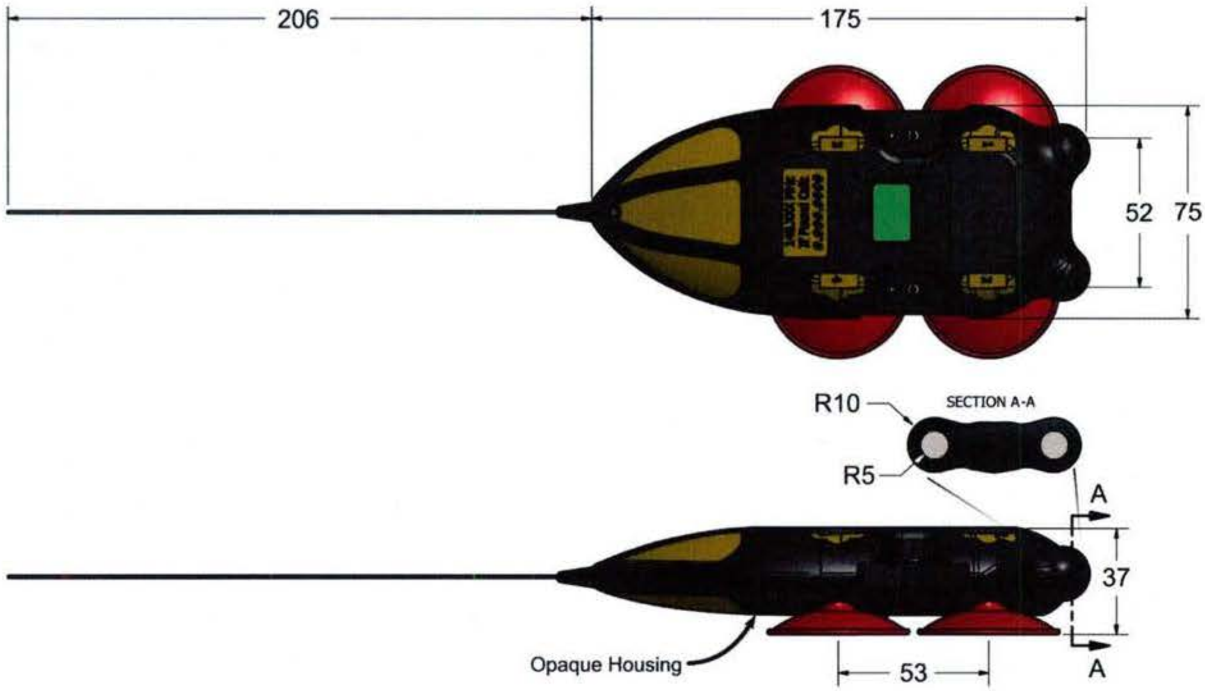

Figure 4 A drawing of the encapsulated DTAG3x V1.0 assembly with suction cups. The external urethane housing acts as a second water barrier in addition to the low viscosity epoxy and urethane used with the sub-assemblies. In addition to acting as a water barrier, the external housing protects the hydrophones, provides the attachment point for the cups and acts as a hydrodynamic fairing. All dimensions in (mm).

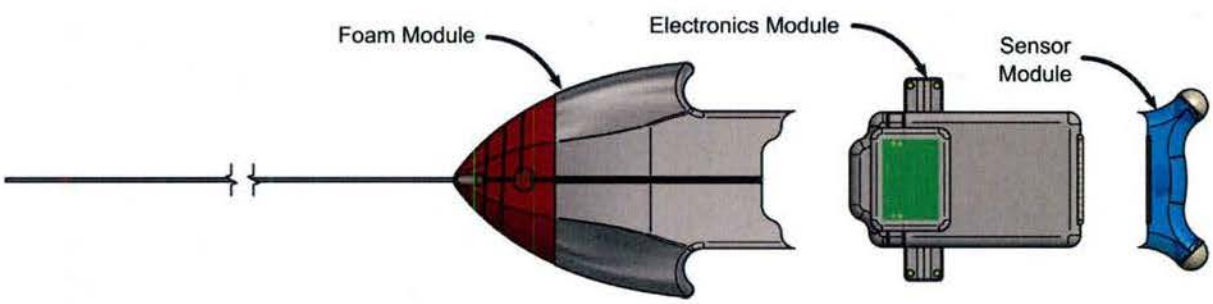

Figure 5 Illustration of the three main subassemblies that make up the DTAG3x V1.0 design.

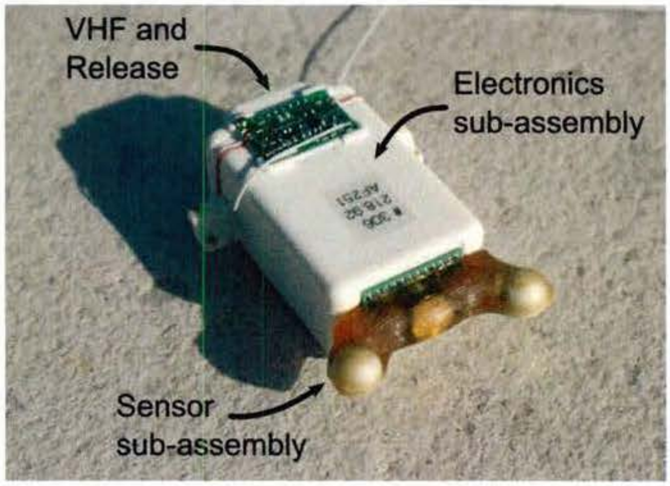

Figure 6 A picture of the updated electronics and sensor sub-assemblies. These design was used with the Core tags and successfully tested this summer.

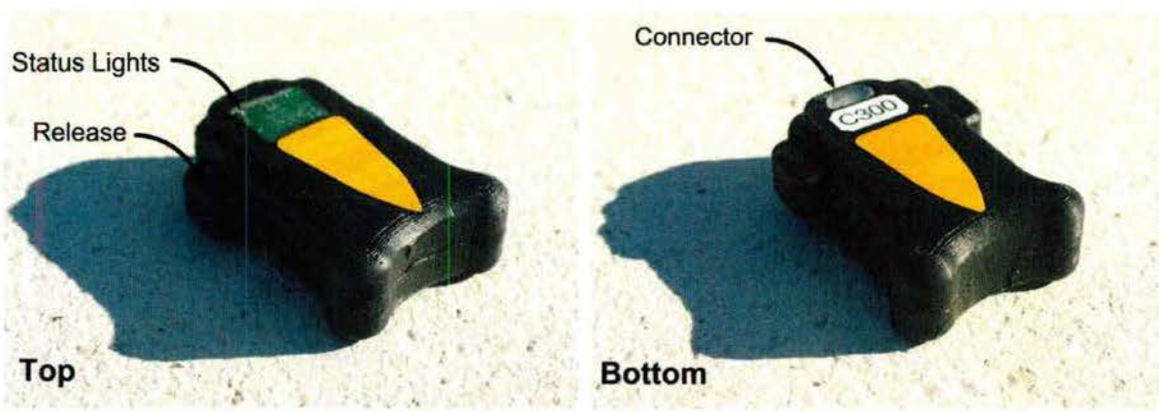

Figure 7 A picture of one of the four completed DTAG3-Core units. The Cores were successfully deployed using the ARTs tag delivery system during field work with bottlenose whales during the summer of 2016.

Figure 8 A picture of one of the DTAG3x-Prototype that was successfully fielded this past summer.